NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2231

COMPARISON OF FATIGUE STRENGTHS OF BARE AND ALCLAD 24S-T3 ALUMINUM-ALLOY SHEET SPECIMENS TESTED AT 12 AND 1000 CYCLES PER MINUTE

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SUMMARY

This report describes the results of axial fatigue tests conducted on 0.032-inch-thick flat-sheet specimens of bare and alclad 24S-T3 aluminum alloy to determine the effect of frequency of loading on the fatigue strengths of these materials. The number of cycles to failure varied from about 150 to over 10,000,000. Tests were conducted using completely reversed axial load at two frequencies of loading: 12 and 1000 cycles per minute.

The tests showed that the fatigue strengths of the materials were slightly less when tested at 12 cycles per minute.

For those specimens which were stressed into the plastic range an investigation was made of the variation of maximum stresses and mean stresses with repeated loading.

INTRODUCTION

Laboratory fatigue tests of materials are usually conducted at as high speed as is practicable. The tests reported in reference 1 were made on high-strength aluminum alloys of European manufacture tested by the rotating-beam method at frequencies of 3000 to 10,000 cycles per minute, and the results show a negligible difference in the S-N curves of these materials for these frequencies. Reference 2 concludes that there is no effect on the fatigue strength of X76S-T aluminum alloy for speeds of testing between 1750 and 13,000 cycles per minute. However, Freudenthal and Dolan (reference 3) point out that on metals which have a low melting point there have been observed appreciable reductions in their endurance limits under very slow repetition of load (reference 4) and that this phenomenon has also been observed to a lesser extent on steel (reference 5).

None of the work cited for aluminum alloys was done at extremely low frequencies, and it was felt that the presence of a soft cladding on a material might reduce its fatigue strength for low-frequency loading. Preliminary tests made at the National Bureau of Standards on 24S-T3 alclad aluminum-alloy sheet indicated that there was some reduction in the fatigue life when the frequency of loading was very low (i.e., 7 cpm). It was therefore decided to conduct a series of tests on 0.032-inch-thick 24S-T3 aluminum-alloy sheet, both bare and alclad, to ascertain whether the frequency effect was significant for these materials.

The present tests were carried out for stresses in both the elastic and plastic regions. The number of cycles to failure varied from about 150 to over 10,000,000. With the type of machine used for these tests, plastic yielding, work-hardening, and temperature changes caused variation in the magnitude of the loads. This resulted in variations of maximum, as well as mean, stresses in the specimens.

The work described in this report was conducted at the National Bureau of Standards under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics.

SPECIMENS AND TESTS

Figure 1 shows the dimensions of the specimens and table 1 shows the mechanical properties of the materials used in the fatigue tests. The specimens were machined from 0.032-inch-thick sheet and were tested in the lever-type machine described as machine a in reference 6. In this machine the load on a specimen is measured by means of electric strain gages located on the loading lever of the machine at diametrically opposite points. The load is varied by driving the end of the lever with an eccentric. The flexibility of the lever is such that about 90 percent of the displacement of the end of the lever is due to the flexing of the lever itself while the remaining 10 percent is due to the deformation of the specimen. Figure 2 shows a specimen clamped in the special steel guide used to prevent buckling of the specimens under compressive load. These guides are similar to those described in reference 7.

Earlier laboratory tests made at the National Bureau of Standards showed that specimens run at about 7 cycles per minute at maximum stresses of about ±40,000 psi failed at an average of 10,000 cycles. Similar specimens run at 1000 cycles per minute at about the same maximum stresses failed at an average of 18,000 cycles, almost twice the average number of cycles required to produce failure at a frequency of loading of

7 cycles per minute. Figure 3 shows these data. The average values shown in figure 3 were obtained by averaging the values of stress and number of cycles.

The initial maximum values of the tension and compression stresses on the specimens were adjusted by successive approximations until the mean stress was less than ±0.5 percent of the maximum stresses. For specimens tested with maximum stresses below ±43,000 psi no difficulty was encountered in keeping the mean stress below ±0.5 percent of the maximum stresses. For maximum stresses above ±43,000 psi it became more difficult to obtain an initial mean stress less than ±0.5 percent of the maximum stresses, and it was observed that the maximum tensile and compressive loads varied during the test. The measured maximum stresses during the early part of tests made on two specimens are shown in figure 4. Figure 5 shows the variation in the calculated mean stress during these tests. The curves of figure 5 were plotted from the measured maximum stresses (fig. 4) with the mean stress defined as half the algebraic sum of the maximum stresses. For these tests the maximum speed was about 1000 cycles per minute, although the number of cycles run between load measurements was so small that the machine usually was accelerating or decelerating during the runs.

It was concluded that plastic flow of the specimens had caused the variation in the mean and the maximum stresses and that a new technique would have to be devised to obtain zero mean stress on a specimen before stressing in the plastic range. To accomplish this, the displacement of the lever at the crank end was measured with a dial indicator, and the lever was placed within 0.001 inch of the center of its stroke before clamping the specimen. However, it was found that, because of the difference in the tension and compression stress-strain curves at high stresses of 24S-T3 aluminum alloy, the lever had to be set somewhat on the tension side of the center before the specimen was finally clamped. This method of establishing the loads on the specimens whose maximum stresses were greater than ±43,000 psi proved satisfactory if the compression load was always applied to the specimens first.

To insure similar amounts of creep from specimen to specimen during initial setting under high stress, the maximum loads were measured after they had been maintained on the specimens for 30 seconds. The maximum stresses were also measured after the specimens had been tested to about one-half their fatigue lives.

Forty-one specimens of bare 24S-T3 aluminum alloy were tested at 1000 cycles per minute with initial maximum stresses of from ±24,800 to ±61,800 psi. Twelve similar specimens were tested at 12 cycles per minute with initial maximum stresses of from ±30,100 to ±60,300 psi.

Thirty-six specimens of alclad 24S-T3 aluminum alloy were tested at 1000 cycles per minute with initial maximum stresses ranging from ±11,300 to ±59,400 psi. Sixteen similar specimens were run at 12 cycles per minute with initial maximum stresses from ±16,800 to ±58,300 psi.

For all cases the initial mean stress was less than 2 percent of the average of the absolute values of the initial maximum stresses. For those cases where the maximum stresses were below ±43,000 psi the initial mean stress was less than 0.5 percent of the average of the absolute values of the initial maximum stresses.

Stress-strain curves in tension and compression in which the load was parallel to the direction of rolling were made for both materials. (See fig. 6.)

RESULTS OF TESTS

The measurements of stress variation made on 20 typical specimens whose initial maximum-stress values were above ±43,000 psi are given in table 2. These measurements include the initial measured maximum tensile and compressive stresses, on the specimens, the initial calculated mean stress, the number of cycles applied to the specimens before the second stress measurements were made, the measured values of the second set of maximum stresses and calculated mean stresses, and the fatigue lives of the specimens. It is seen that the change in the mean stresses varied from 0.2 percent of the average of the absolute values of the initial maximum stresses for specimen 3 to more than 5 percent for specimen 75, with the average change for all specimens being 2.0 percent. The change in the stress amplitude (i.e., the average absolute values of the maximum stresses) varied from approximately 0.1 percent for specimen 42 to 7.8 percent for specimen 45, with the average change in the stress amplitude for all specimens being 3.6 percent of the average of the absolute values of the initial maximum stresses.

Figures 7 and 8 show S-N curves of the alclad and bare 24S-T3 aluminum-alloy specimens tested at 1000 cycles per minute. The results obtained for these materials tested at 12 cycles per minute are superposed on these figures for comparison. Figure 7 contains, in addition, the averages of the data obtained from earlier tests conducted on alclad 24S-T3 aluminum alloy, that is, the averages of the data shown in figure 3. The values of stress plotted in figures 7 and 8 are the averages of the absolute values of the initial maximum tensile and compressive stresses. From the curves faired through the data measured at 1000 cycles per minute shown in figures 7 and 8, it can be seen that the results of the tests made at 12 cycles per minute tend to fall toward the left edge of the scatter of those made at 1000 cycles per minute. The data shown in figure 3, when plotted in figure 7, fall within the scatter of the data of figure 7.

CONCLUSIONS

The results of fatigue tests on bare and alclad 24S-T3 aluminum-alloy specimens made at 12 and 1000 cycles per minute indicated that:

1. The fatigue strengths of both materials were slightly lower at the frequency of 12 cycles per minute.

2. A quantitative estimate of the effect of low-frequency loading on the fatigue strengths of these materials cannot be made because the effects are small compared with the observed scatter.

National Bureau of Standards
Washington, D. C., December 19, 1949

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TABLE 1.- MECHANICAL PROPERTIES OF MATERIALS

Material	Young's modulus (psi)		0.2-percent-offset yield strength (psi)		Ultimate strength (psi)	
	Tension	Compres-sion	Tension	Compres-sion	Tension	Compres-sion
24S-T3	10.7×10^6	10.6×10^6	55,600	46,000	73,600	----
Alclad 24S-T3	10.2	10.3	49,600	46,400	67,400	----

TABLE 2.- MEASURED MAXIMUM STRESSES AND CALCULATED MEAN STRESSES FOR SOME TYPICAL ALUMINUM-ALLOY SPECIMENS

TESTED AT INITIAL MAXIMUM STRESSES GREATER THAN ±43,000 PSI

Specimen	Initial stresses (psi) in -		Initial mean stress (psi) (1)	Cycles to approximately half life	Stresses at approximately half life (psi) in -		Mean stress at approximately half life (psi) (1)	Cycles to failure
	Tension (1)	Compression (1)			Tension (1)	Compression (1)		
Bare 24S-T3 tested at 1000 cycles per minute								
12	44,600	44,600	0	13,600	44,700	44,300	+200	26,860
16	44,400	44,700	-150	13,600	44,400	44,100	+150	28,440
3	49,100	49,500	-200	3,905	51,400	51,600	-100	5,990
32	49,900	49,500	+200	3,900	51,300	52,600	-650	6,880
1	55,200	54,900	+150	950	56,900	60,800	-1,950	2,270
60	56,000	56,300	-150	950	57,600	62,200	-2,300	2,460
Bare 24S-T3 tested at 12 cycles per minute								
2	58,300	59,900	-800	50	60,500	63,800	-1,650	295
5	53,200	54,400	-600	600	53,800	55,800	-1,000	1,520
x	47,700	47,100	+300	2,540	48,700	45,300	+1,700	5,190
Alclad 24S-T3 tested at 1000 cycles per minute								
17	43,100	43,200	+50	6,900	45,700	41,500	+2,100	13,670
29	43,600	43,600	0	6,800	44,400	42,600	+900	16,200
36	46,900	47,500	-300	5,200	46,300	50,000	-1,850	7,210
42	46,900	47,800	-450	5,200	46,400	48,200	-900	10,580
50	51,100	51,100	0	3,420	52,900	51,400	+750	6,100
75	51,100	50,600	+250	3,420	55,100	49,300	+2,900	6,600
71	54,600	55,400	-400	790	58,200	58,400	-100	2,510
58	54,900	54,100	+400	780	59,700	57,200	+1,250	2,030
Alclad 24S-T3 tested at 12 cycles per minute								
49	57,400	59,300	-950	85	59,700	63,800	-2,050	650
45	57,000	57,800	-400	85	60,500	63,200	-1,260	400
20	53,200	52,400	+400	900	55,200	56,000	-400	1,710

[1]Tension, +; compression, -.

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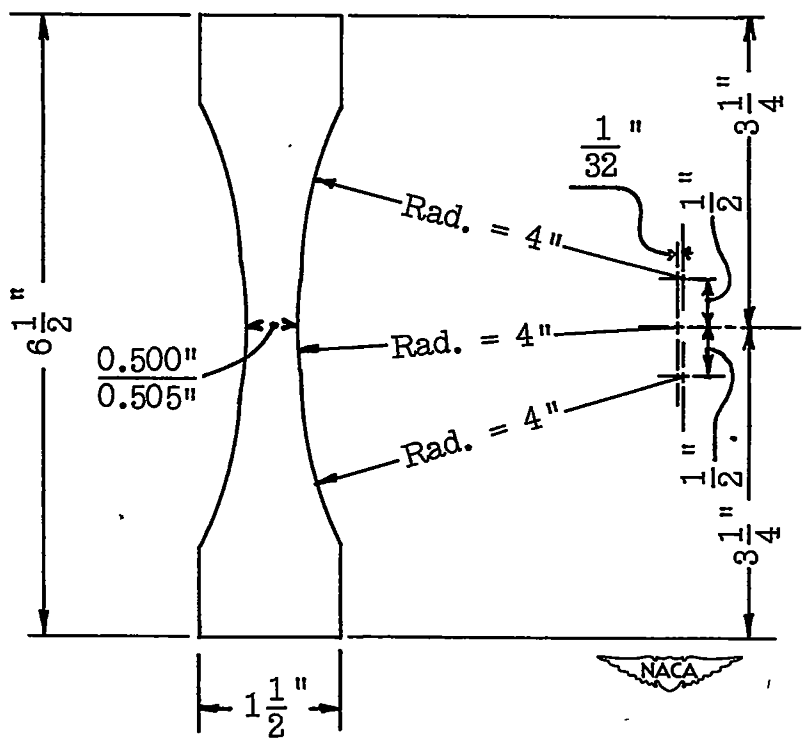

Figure 1.- Fatigue specimen. Thickness as rolled.

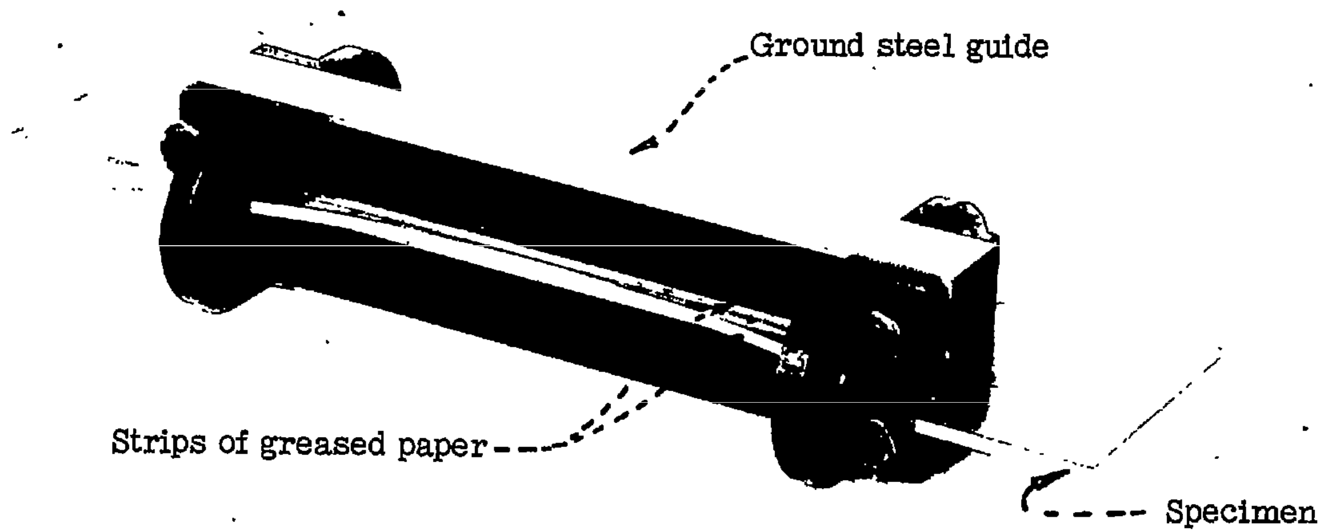

Figure 2.- Typical specimen in guide.

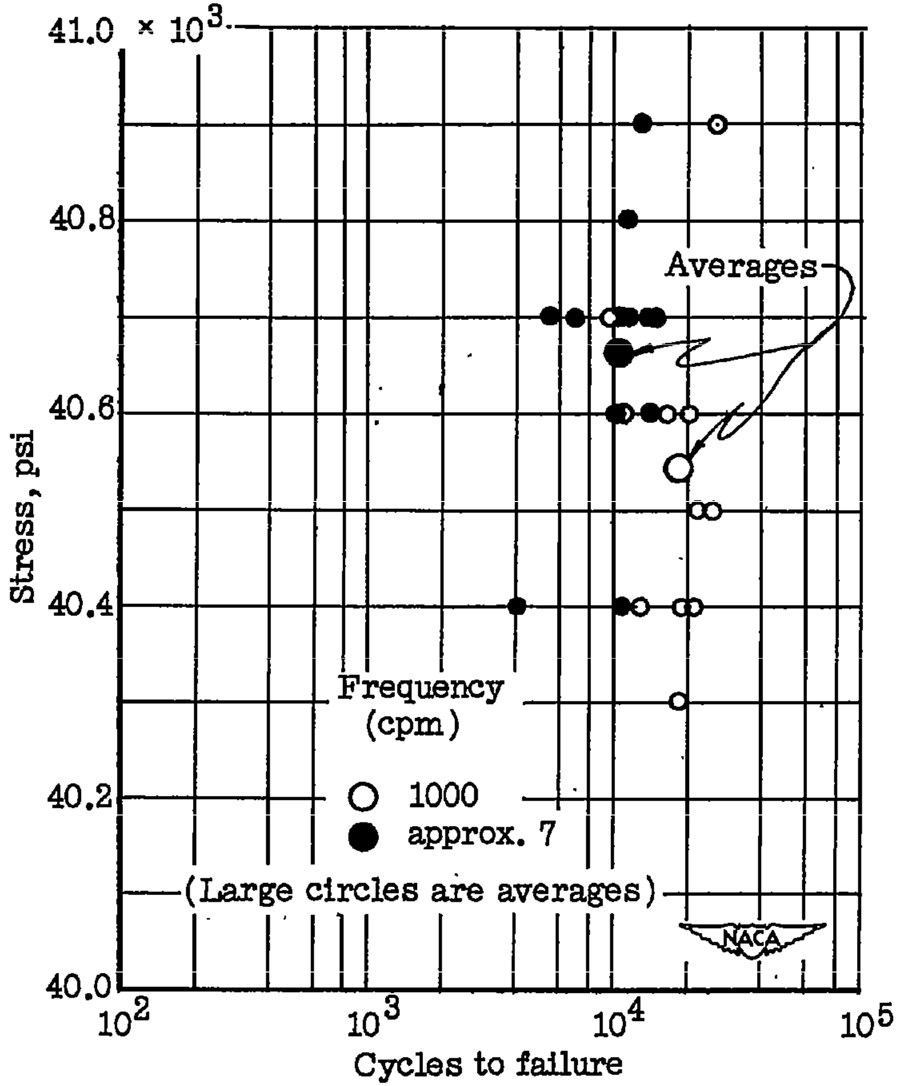

Figure 3.- Early tests. Comparison of results of tests made at 1000 cycles per minute and approximately 7 cycles per minute on alclad 24S-T3 aluminum-alloy sheet.

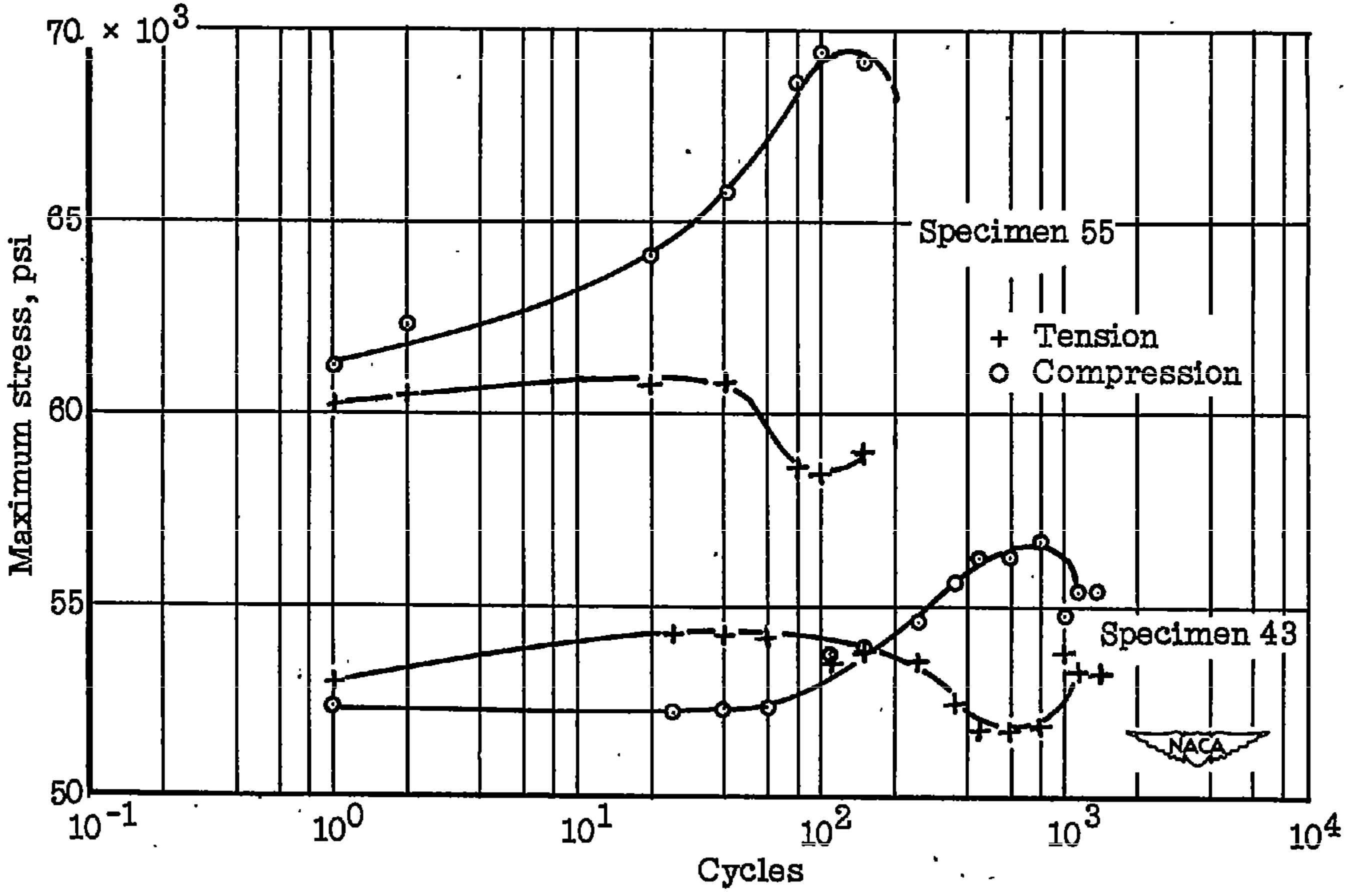

Figure 4.- Variation of measured maximum stresses with number of cycles run for two alclad 24S-T3 aluminum-alloy specimens tested with maximum stresses above ±43,000 psi at about 1000 cycles per minute.

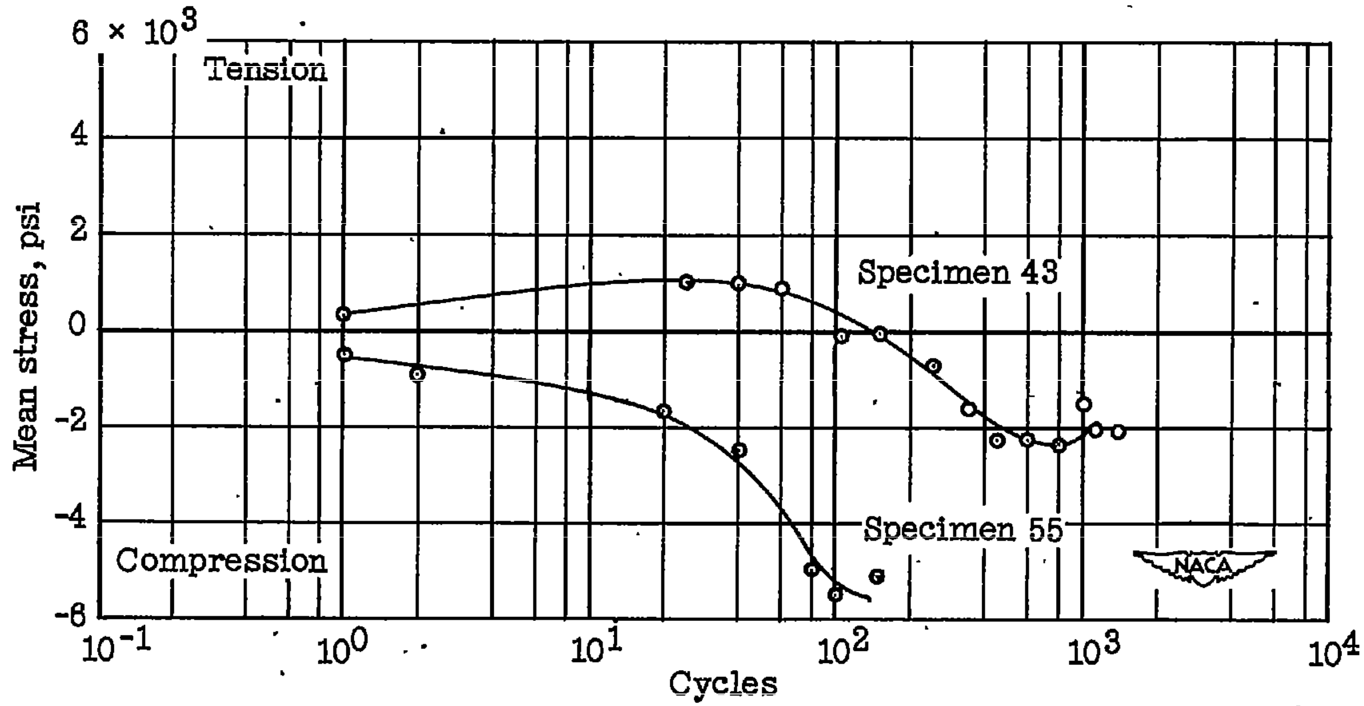

Figure 5.- Variation in mean stress of two specimens of alclad 24S-T3 aluminum alloy tested with maximum stresses above ±43,000 psi at about 1000 cycles per minute.

$$\text{Mean stress} = \frac{\text{Maximum tensile stress} + \text{Maximum compressive stress}}{2}.$$

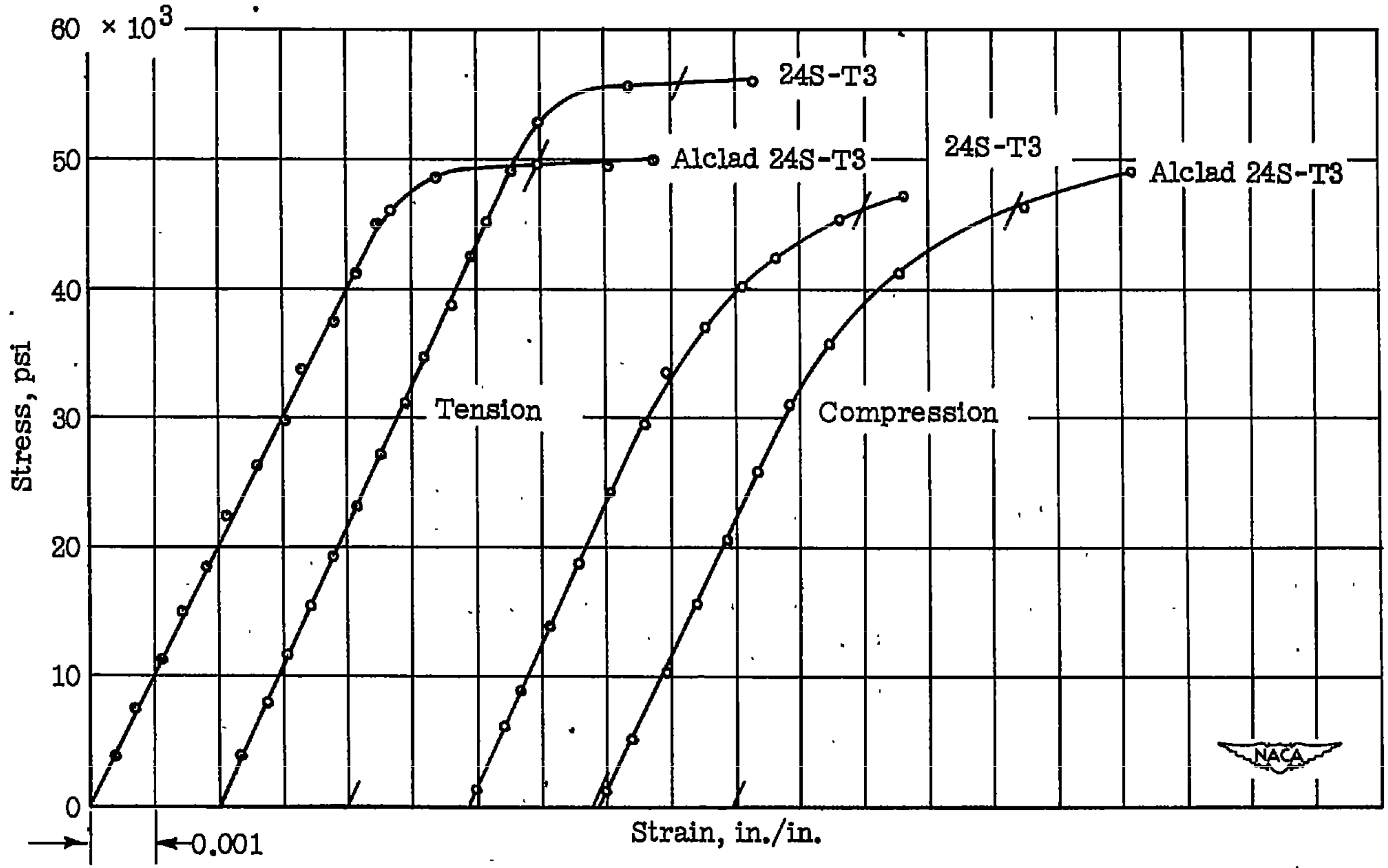

Figure 6.- Stress-strain curves for materials used. Load parallel to rolling direction.

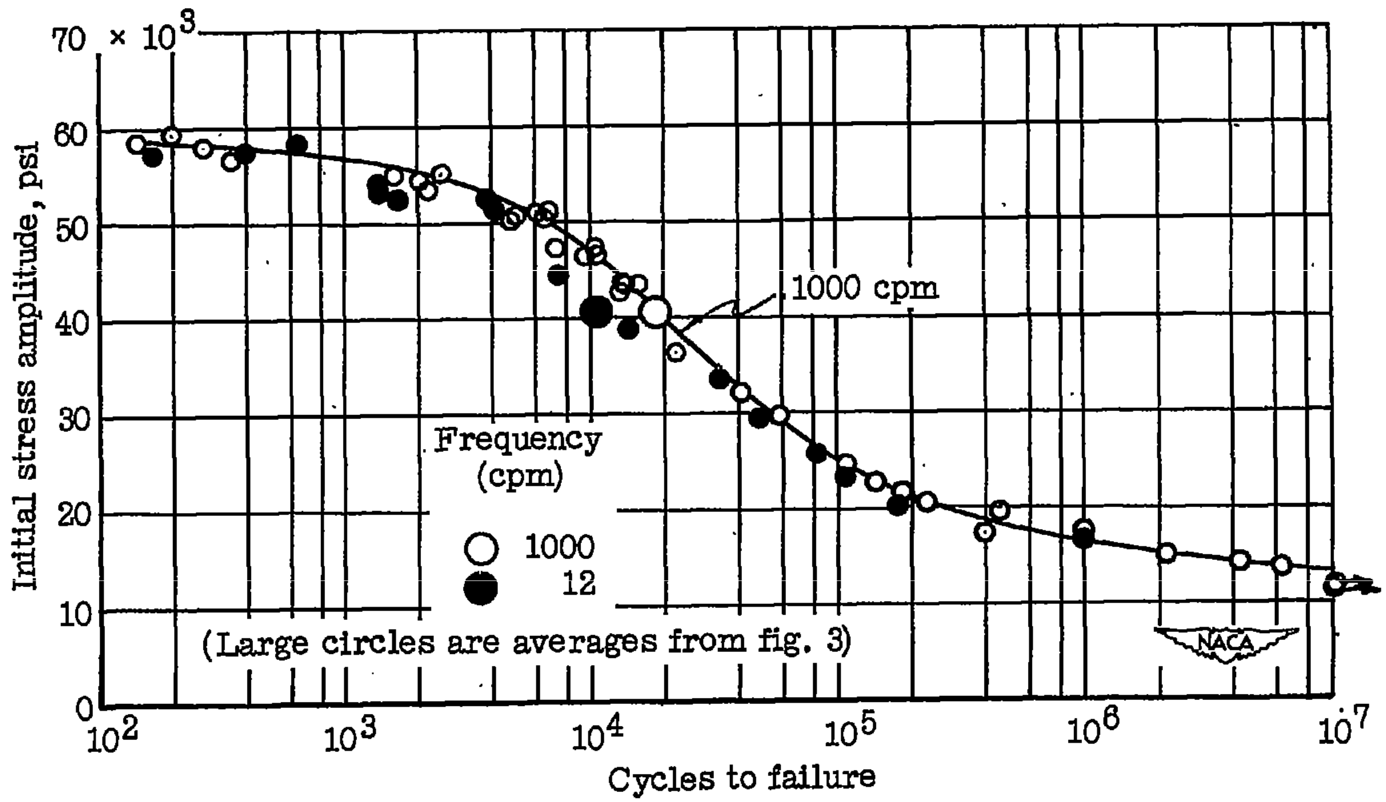

Figure 7.- S-N curve for alclad 24S-T3 aluminum alloy tested at 1000 cycles per minute and results of tests made at 12 cycles per minute. Stress amplitude $= \dfrac{\text{Maximum tensile stress} - \text{Maximum compressive stress}}{2}$.

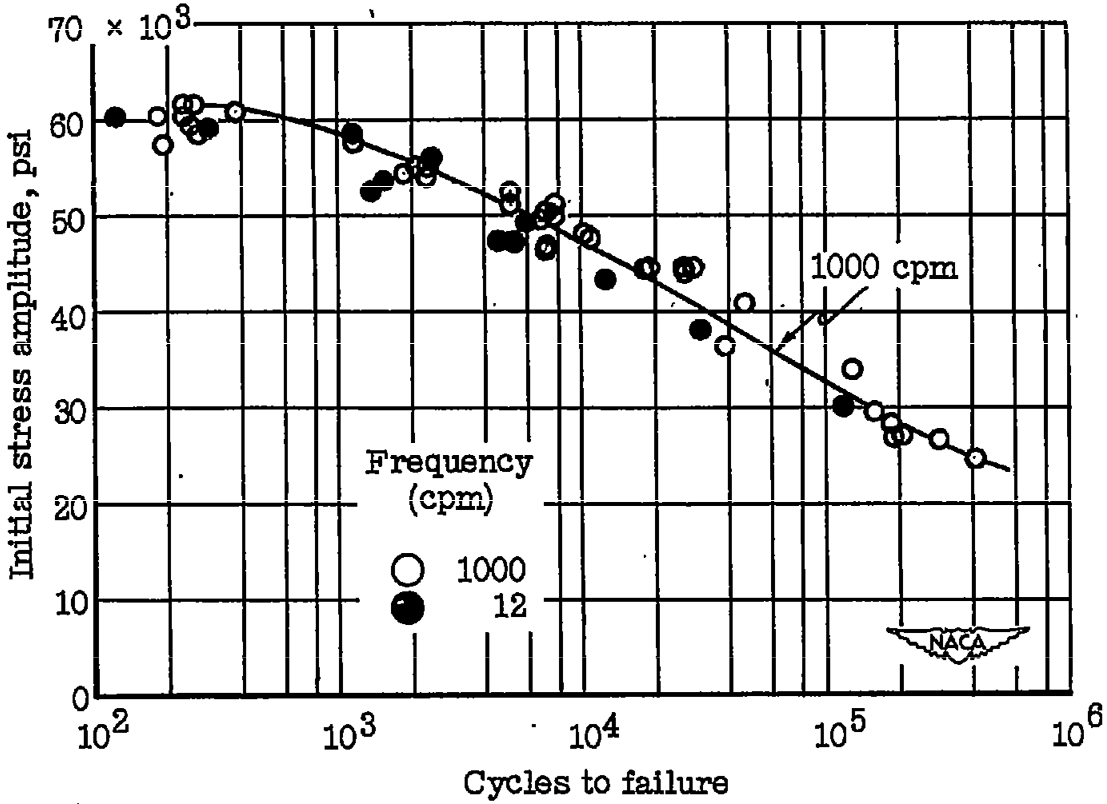

Figure 8.- S-N curve for 24S-T3 aluminum alloy tested at 1000 cycles per minute and results of tests made at 12 cycles per minute. Stress amplitude $= \dfrac{\text{Maximum tensile stress} - \text{Maximum compressive stress}}{2}$.

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